In Collaboration with
the Energy Transitions
Commission

WORLD
ECONOMIC
FORUM

Joint Policy Proposal to Accelerate the Deployment of Sustainable Aviation Fuels in Europe

A *Clean Skies for Tomorrow* Publication

WHITE PAPER

OCTOBER 2020

Cover: Unsplash/Kumiko Shimizu

Contents

Inside: Unsplash/Jordan Sanchez; Unsplash/Danist; Getty images/ollo; Getty images/greenleaf123; Unsplash/Joakim Honkasal; Unsplash/Inspirationfeed

Executive Summary

The World Economic Forum's *Clean Skies for Tomorrow* (CST) initiative, established in 2019, is a community platform for leaders throughout aviation's value chain to facilitate the transition to net-zero flying by mid-century. The CST Coalition is a public-private partnership that is driving a shift to zero-emissions aviation through sustainable aviation fuels and other clean propulsion technologies. In the context of the European Green Deal, the European members of the CST community have developed a joint strategy for accelerating the transition to climate neutrality in aviation in Europe, with a particular focus on increasing the uptake of sustainable aviation fuel (SAF) over the next decade. Despite the COVID-19 pandemic, they remain committed to working with policy-makers to advance that agenda.

Aviation now accounts for 3.6% of total greenhouse gas (GHG) emissions in the EU and its contribution is set to continue to increase in the coming decades without coordinated action from industry and policy-makers. While a range of interventions will be necessary to seize all opportunities to reduce emissions from aviation and reverse this trend, including technology improvements and breakthroughs, there is at present an urgent need to specifically support the uptake of sustainable aviation fuel (SAF).

SAF is indispensable to achieve carbon neutral aviation, especially for long-haul flights. It has the significant financial advantage of not requiring any major new equipment or infrastructure investment, as it can be blended with conventional jet fuel. Today's commercial production is, however, only approximately 0.05% of total EU jet fuel consumption[1] and the current pace of growth is nowhere near what it should be to meet Europe's climate objectives.

The key issue currently preventing the production and use of SAF from taking off is the price gap between fossil-based jet fuel and SAF, which remains prohibitively large. The SAF supply chain faces a "chicken and egg" problem with supply and demand: costs will come down if production scales up (thanks to learning curve effects and economies of scale), but fuel providers are lacking a strong demand signal to increase production and demand is low due to the high price premium.

As the European Union and the UK refine their strategy to deliver on their respective net-zero emissions targets, it is crucial that they establish a coherent and decisive policy package, including public financial backing, to simultaneously drive up SAF production and consumption and unlocking cost reductions that will benefit the whole aviation sector.

To this end, European CST members have devised a policy package to support the adoption of SAF in Europe that includes measures aimed at increasing SAF supply and demand. It is vital that these policies work hand in hand to simultaneously boost production and consumption of SAF in a strategic and sequenced manner and that they are coherent with the technically feasible pace of production ramp up to avoid supply bottlenecks and price volatility.

A coherent policy package for SAF should also be feedstock and technology neutral to allow for a range of bio-based and synthetic SAF production routes, only distinguishing fuels based on technology maturity levels (with greater support required for earlier-stage technologies) and on appropriate lifecycle carbon emissions and broader sustainability requirements (especially in terms of land use and biodiversity impact). Given supply constraints, sustainable bio-feedstocks should be prioritized for use in aviation as alternative decarbonization options are extremely limited.

The key to driving up investment in SAF production is to provide fuel providers – and their financiers – with greater certainty on future markets. In 2020, the EU Commission and the Government of the UK should announce aviation policies to be enforced in the second half of the decade. This would incentivize investment in SAF production plants over the next five years. Policy frameworks should then remain in place for at least 10-15 years to ensure projects have a solid long-term business case.

Overview of recommended SAF ramp-up policy package

In this context, European CST members recommend the following package of policies to support the technological development and early deployment of SAF (priorities 1-3) and drive up SAF demand (priority 4). While support to fuel providers is vital to increase production volumes over the next 10 years, it will be insufficient to provide a strong business case for the development of SAF plants at an industrial scale in the absence of robust demand signals providing some certainty on future demand levels.

1. **Support innovation to bring lignocellulosic/ biowaste and power-to-liquid pathways to market.** Given limits on future supply of feedstock, scaling up SAF uptake in Europe to meaningful levels will not be possible by relying exclusively on the technology pathways that are commercially available today. Therefore, further research and development support is required for the technologies with the highest potential for cost disruption and with the most sustainable sources of feedstock – i.e. biofuels from lignocellulosic feedstocks and power-to-liquid pathways.

2. **Support SAF provision through price floors guaranteed by government during the early stages of deployment.** The existence of a market for SAF is currently limited due to the price difference between SAF and conventional jet fuel. Policy mechanisms to secure a price floor for SAF output will be crucial for making new SAF plants economically viable, especially in the early stages of deployment while regulations incentivizing SAF demand (e.g. fuel mandates) are not yet in place.

3. **Support early deployment by de-risking investment in the first wave of production facilities.** Even in a favourable policy context, investment in first-of-a-kind production facilities will entail a level of technology and commercial risks that lead to high financing costs and long timelines to raise capital for SAF plants. This will likely remain true for the following wave of projects during the first decade of SAF deployment. Different forms of public financial support from public investment funds, national government, regional development banks and international financial institutions should be used to help de-risk these projects and secure upfront private capital investment.

4. **Announce in 2021 a SAF blending mandate for European aviation to be enforced no later than 2025 with a blending level increasing progressively through 2050.** The obligation should initially apply to intra-European Economic Area (EEA) flights, ideally encompassing the EU and the UK. This will serve as a powerful incentive to boost production and secure investment in SAF. Public financial support will be required to compensate for the effect of competitive distortions, especially on intra-EEA feeder flights. Additional measures will, however, be needed by 2030 at the latest to ensure the decarbonization of long-haul aviation. Further work will be required to determine the exact appropriate design of such a blending mandate as well as appropriate levels of blending through time given the feasible ramping up of SAF production.

Introduction

Implications of the COVID-19 pandemic

This proposal was initially developed prior to the COVID-19 pandemic. The aviation industry finds itself in a difficult economic situation due to the exceptional circumstances caused by the global pandemic, which has brought most major economies to a standstill. The immediate priority for the sector is to navigate this challenge. It will take several years for the aviation industry to recover from this unprecedented downturn. Decarbonization, however, remains a critical issue for the future of aviation and should remain the horizon towards which airlines, airports, manufacturers and fuel providers continue to progress, with the support of government. European members of the *Clean Skies for Tomorrow* initiative remain committed to working with policy-makers to advance that agenda. The economic stimulus packages that Member States and the European Union will need to implement to support the recovery of the European economy over the next five years can contribute to advancing the low-carbon transition of European aviation. The recommendations outlined in this note can be implemented in that context.

The CST initiative is a coalition of leading airlines, airports, manufacturers and fuel providers working together to find solutions for reaching net-zero emissions from global aviation by mid-century. It provides a crucial platform for top executives to align on a transition pathway for the industry to achieve carbon-neutral flying and to take practical steps towards that goal. It is a key element of the Mission Possible Platform – a broader international coalition working to decarbonize harder-to-abate heavy industry and transport sectors.

Over the last year, the European members of the CST community have developed in partnership a strategy for accelerating the transition to carbon neutrality in aviation in Europe, with a particular focus on developing pathways to accelerate the uptake of sustainable aviation fuels (SAF) over the next decade.

The European CST members welcome the European Commission's European Green Deal initiative and support the EU's target of net-zero emissions by 2050. This community paper was jointly developed to outline agreed key guiding principles for European policy-makers to consider as they prepare EU and national budgets to support the European economic recovery and as they start drafting EU Renewable Fuels regulations for aviation. This document lays out a set of policy recommendations that can accelerate the uptake of SAF in Europe by 2030 and outlines a coherent set of supply-side and demand-side measures necessary for the success of the European Green Deal with regards to aviation. The *Clean Skies for Tomorrow* Coalition stands ready to exchange with the Commission, Member States and MEPs on our recommendations.[2]

Action is needed now

Before the COVID-19 pandemic, emissions from aviation accounted for approximately 2.5% of total global energy-related CO_2 emissions, more than the entire national contributions of Brazil or Germany.[3] This share was even higher in the EU, where aviation accounts for 3.6% of total GHG emissions.[4] Global emissions are expected to recover from the current crisis and continue to grow, increasing by 83% to reach 1.8 Gt CO_2 per annum by 2050, with approximately 10% coming from the EU.[5,6] Changing this trajectory is essential to ensure that aviation plays its role in delivering the Paris climate agreement objectives. It will require collective action from governments and industry players throughout the entire aviation value chain.

Policies to support the transition to net-zero emissions in aviation must be devised within an overarching strategy for decarbonizing passenger and freight mobility in the EU. This should encourage greater system efficiencies throughout different transport modes and optimize for emissions reduction throughout the full mobility system (e.g. with regards to the allocation of limited sustainable bio-resources between sectors). This includes encouraging modal shifts to ensure passengers use low-carbon transport options as a priority wherever possible. This paper encourages the European Commission to ensure new policies relating to aviation are consistent with a general framework for ensuring carbon neutrality throughout the continent by 2050.

For aviation, there will be no "silver bullet" decarbonization solution. The industry will need to rely on a range of measures that will work hand in hand: carbon compensations in the short to medium term (e.g. via the EU ETS and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)), efficiency improvements (including through optimized air traffic management and improved aircraft technology) as well as a shift to low and eventually zero-carbon energy sources.

CST members are committed to doing their part in decarbonizing aviation and are working alongside other stakeholders, including policy-makers, to shape a cost-effective pathway to net-zero emissions by mid-century. Policy support at the EU level is crucial for the entire industry to meet this objective on time in Europe. It will also enable Europe to pursue an ambitious SAF pathway and support the aviation sector's global transition by accelerating technology development and cost reductions.

Seven policy pillars for a more sustainable EU aviation ecosystem

1. *Create a new long-term policy framework to support the production and consumption of SAF in Europe.*

   – For reasons detailed below, SAF will play a crucial role in decarbonizing aviation in Europe and globally, as it will remain the main driver of carbon emissions reductions in aviation for the foreseeable future. The European Green Deal – and the economic recovery stimulus package developed in its wake – represents a unique window of opportunity to support the rapid acceleration of SAF uptake in Europe. The rest of this document is therefore focused specifically on this subject.

2. *Support the development of radical new aircraft systems, including electric and hydrogen planes.*

   – Aircraft manufacturers are currently developing radical aircraft redesigns which could bring down energy consumption per kilometre travelled by 30%-40% by 2030 (e.g. using advancements such as laminator flow controls and open rotor engines)[7] and possibly more in the longer term, through innovations like blended wing bodies and new materials.

   – These radical changes are likely to be required to shift to new forms of propulsion via electric or hydrogen planes.[8] These technologies will be vital for decarbonizing short-to-medium haul aviation and will need to be coupled with a rapid, sustained increase in renewable electricity generation in Europe.

   – These solutions are at earlier stages of development and would benefit from innovation funding for the development, at-scale demonstration and early deployment phases. This will require support for aircraft manufacturing and energy provision infrastructure in airports.

3. *Complete the Single European Skies programme to ensure maximum efficiency of European air traffic.*

   – It is estimated that completing the Single European Sky project – i.e. merging the 15 existing functional airspaces – can reduce the environmental impact of aviation by 12% through better regional air traffic management (ATM).[9] Practically, ATM entails measures such as optimizing routing and air traffic flow management, minimizing flight distances, cutting aircraft waiting times, and improving load factors.[10]

   – Completing the Single European Skies programme, by merging the different functional airspace blocks, is one of the most cost- and time-effective ways of delivering emissions reductions for European aviation in the short term.

4. *Support fleet renewal for European airlines to improve energy efficiency.*

   – On average, each new generation of aircraft is roughly 15% to 20% more efficient than the previous generation.[11] This technological progress has been essential to moderate the rise in carbon emissions from aviation relative to the pace of growth of the industry over the past decades. Energy efficiency gains are expected to continue in the coming years thanks to improvements in aircraft design (e.g. composite structure components) and in engines. New aircraft design could reduce jet fuel consumption per aircraft by 10%-20% in the early 2020s.

   – The lifespan of a passenger aircraft is usually between 25 and 28 years[12] which creates a technology lock-in issue, slowing the deployment rate of new technologies. Retrofitting is likely to yield only 6%-9% emissions reductions.[13]

   – Governments can play a role in supporting fleet renewal for European airlines, in particular by accelerating the retirement of the oldest and most polluting aircraft, through appropriate financial incentives and aircraft regulations.

- Additionally, improved airport infrastructure could bring added benefits, for instance, through the deployment of fixed electrical ground power units (i.e. equipping airport gates with power and preconditioned air) to run aircrafts while grounded instead of relying on jet fuel. This is expected to save an average of 5.6kg CO_2 per minute on the ground.[14]

5. *Pursue existing carbon pricing policies and strengthen them after the sector recovers from the COVID-19 pandemic.*

   - Carbon is already priced through a range of government policies globally, regionally, and nationally. From 2021, growth in international air travel is covered by the UN's "carbon offset and reduction scheme" (CORSIA). Flights in Europe have been part of the region's "Emissions Trading System" since 2012.

   - Carbon pricing is likely to only have a limited impact on SAF uptake in the short term (given that current levels of carbon pricing are too low to trigger a fuel switch), but could play a greater role over time as carbon prices increase and the premium cost of SAF decreases. In the meantime, it also constitutes an important driver for other decarbonization measures in the aviation industry beyond fuel choice through incentivizing energy efficiency.

   - The EU ETS should be strengthened to send the right incentives to decarbonize and increase SAF use.[15] That should, however, happen after the recovery from the COVID-19 pandemic, given that a short-term rise in prices could have a significant negative effect on a sector already struggling with the most significant crisis in its history.

6. *Support the implementation of CORSIA.*[16]

   - CORSIA constitutes a unique example of international coordination to drive the decarbonization of a global industry. The successful implementation of this scheme will be essential for the aviation industry and could also serve as a model for other global sectors.

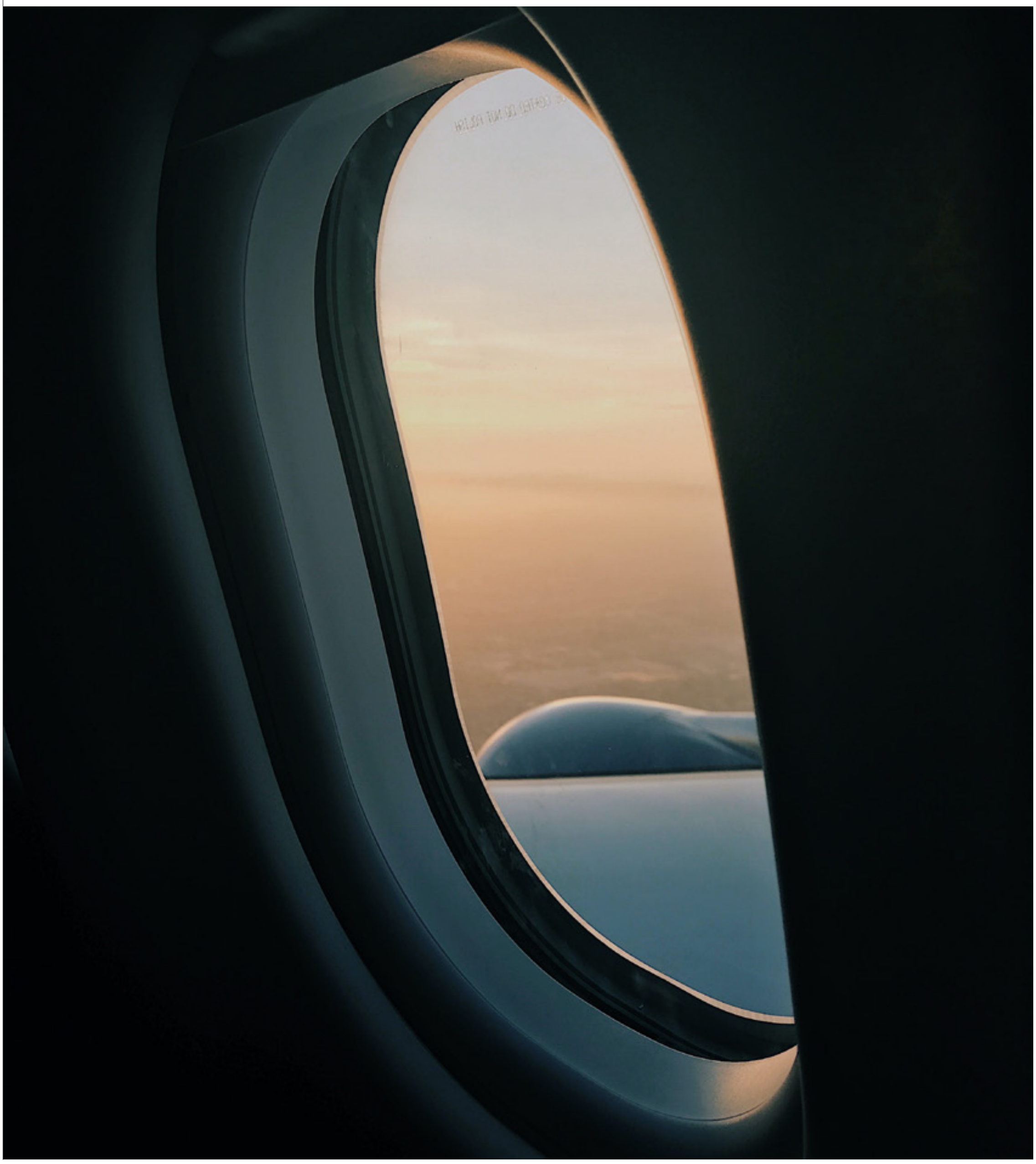
   - The determination of the ICAO Technical Advisory Board on the set of eligible offsetting schemes for the voluntary pilot phase of the CORSIA framework from 2021-2023 is an important milestone. European CST members support the recommendations established in the Emissions Unit Eligibility Criteria (EUCs) and encourage these standards to be upheld throughout the CORSIA implementation period.

7. *Continue to participate in international diplomatic efforts to reach net-zero emissions from global aviation by mid-century.*

   - The EU and the UK – especially in the context of COP26 – should continue to support international agreements for reducing greenhouse gas emissions and improving environmental standards in the aviation sector, building on the momentum created by the agreement on the CORSIA framework. They should collaborate with other countries to progress towards net-zero emissions from global aviation by mid-century.

Below: Unsplash/Jon Tyson

1 The imperative to increase SAF uptake



❝ **There is an urgent need for new regional policy measures to incentivize SAF production and consumption to rapidly increase the scale of production.**

SAF – i.e. "drop-in" fuels that are initially low- and eventually zero-carbon over their lifecycle – will play an essential role in achieving carbon neutral aviation. These have the significant financial advantage of not requiring any major new equipment or infrastructure investment, as they can be blended with conventional jet fuel and used in the existing engines and fuel infrastructure.

The existing level of commercial production of approx. 35 million litres per year in the EU (~0.05% total EU jet fuel consumption) is, however, far smaller than is required for SAF to be deployed at scale.[17] The current pace of growth is nowhere near what it should be to meet climate objectives. The main reasons for that slow pace of deployment are the high cost differential between conventional jet fuel and SAF (+100%-200% for the most readily available technologies at average pre-COVID oil prices[18]) and the level of technology readiness of certain conversion pathways.

There is an urgent need for new regional policy measures to incentivize SAF production and consumption to rapidly increase the scale of production, unlock learning curve effects and economies of scale, and drive cost reductions that will then benefit the global aviation industry.

A European strategy for increasing SAF uptake is required for the following reasons:

– **Current climate commitments are insufficient:** The aviation industry has committed to halving emissions by 2050 and has agreed to offset any growth in emissions from current levels via the CORSIA mechanism. These commitments, however, remain insufficient for achieving the target of carbon neutrality set in the European Climate Law.

– **Offsetting is only a transitional decarbonization option:** Today, compensations from the land use sector or from easy-to-abate sectors represent an essential lower-cost route to emissions reductions for the aviation industry, which will be usefully incentivized and regulated by CORSIA. They do not, however, constitute a long-term decarbonization solution: afforestation – and hence carbon credits from land use changes – will eventually reach a plateau as land to grow new forests gets scarce, while the volume of non-land use carbon credits should dry up to ensure that the global economy heads towards net-zero emissions.

– **Energy efficiency improvement can only be a part of the solution:** Improvements in engine and airframe efficiency, along with air traffic optimization and other operational improvements, can significantly reduce the rate of growth in carbon emissions from aviation, and must be pursued aggressively. These measures, however, have a maximum CO_2 emissions reduction potential of only 15% and 30%-45%, respectively. Reaching net-zero emissions will therefore require a shift to alternative low-carbon energy sources – either SAF or electric propulsion (battery electric or hydrogen).[19]

- **Electric and hydrogen planes are unlikely to be a solution for long-haul aviation in the foreseeable future:** Battery electric and hydrogen planes are likely to play a vital role over short to medium distances and enable that segment of aviation to be zero-emissions at the point of use. But without a dramatic and currently unforeseeable improvement in battery energy density, or a fundamental redesign of aircrafts to accommodate for large hydrogen volumes, these technologies will not be able to power long-haul aviation. The path to net-zero-carbon aviation therefore relies heavily on some combination of biofuels and synthetic/electro-fuels ("power-to-liquids"), collectively identified as SAF.
- **SAF is not currently cost-competitive leading to slow progress in uptake:** At present, SAF production represents less than 0.05% of EU jet fuel consumption. The price remains at least 100%-200% higher than kerosene for the most readily available technologies (at pre-COVID-19 oil prices), and significantly more for others, precluding a large-scale uptake in a highly cost-competitive sector. While new capacity is set to come online over the next five years, considerably more is required to achieve meaningful decarbonization (e.g. a multiplication factor of more than 200x current production to reach even 10% of EU aviation fuel consumption).
- **European coordination of aviation policies is required:** In the absence of harmonized EU policy, some European countries are unilaterally introducing regulations – e.g. in the form of blending mandates, fuel taxes, and flight taxes – which make a complex and uneven regulatory landscape for the industry, risking intra-European competitive distortions. Pursuing an EU and UK-wide policy framework that provides certainty over a longer time horizon would be far more effective. It could then inspire extension to neighbouring hubs (e.g. the Middle East) and a progressive ramping-up of commitments within ICAO.

Below: Getty images/Nico El Nino

2 Sourcing SAF from Europe

Multiple SAF production pathways already exist or are in the process of being developed, using different types of bio or synthetic feedstocks. Each type of feedstock entails a different level of lifecycle GHG emissions reduction and a different set of sustainability risks. A given type of feedstock can generally be used through different conversion pathways and vice-versa a given conversion pathway can generally use different types of feedstock. It is essential to understand this complexity to appropriately regulate and support the development of SAF. Policy frameworks should reflect these differences and support the development of highly sustainable and scalable forms of SAF, while navigating potential short-term trade-offs between availability and sustainability.

There are currently seven ASTM-certified technologies to produce SAF, with several others in the process of being developed and approved. These pathways can convert biomass and synthetic feedstocks to biofuels that can be blended with jet fuel. The dominant technology today is the Hydro-Processed Esters & Fatty Acids (HEFA) pathway, which typically uses oil-based feedstocks. In addition, the technologies most likely to be able to scale up production over the next 10 years are: Gasification + Fischer-Tropsch (F-T) and Alcohol-to-Jet (ATJ).[20] Given technology readiness, production from other more novel conversion pathways, including power-to-liquid pathways, are likely to remain limited in this decade, but could play a major role further down the line.[21]

2.1 Crop-based biofuels

The potential to sustainably produce SAF from crop-based biomass, i.e. first generation biofuels, is limited. The implementation of the Renewable Energy Directive (RED-I) has led European transport to progressively increase its consumption of biofuels from crop-based sources over the last two decades. This policy has resulted in the significant increased production of crops for biofuel generation in Europe as well as a rise in imported crops. From 2012 to 2018, EU member states' imports of palm oil rose from 1.53 to 2.57 million tonnes, reaching approx. 15% of total biodiesel consumption.[22]

The revised RED-II directive, however, limits use of crop-based biofuels. The large-scale deployment of crop-based biofuels has led to adverse environmental consequences in some regions. Some biofuels produced from crop-based sources have failed to deliver the expected net GHG emissions reductions due to indirect land-use change (ILUC) (e.g. deforestation), while also competing with food/feed production and having a negative impact on biodiversity. Some energy crops can still be produced sustainably, but increased demand can incentivize unsustainable practices. The potential for a significant increase in energy crop production is therefore doubtful given the opportunity cost for land use in a context of fast-growing global population, related land requirements for food production, and the imperative to accelerate afforestation to fight climate change.

In this context, European policy should be tightened to ensure that any crop-based biofuels' use is subject to the highest possible sustainability criteria, including a robust assessment of ILUC, displacement effects of food/feed crops, and lifecycle carbon sequestration compared to other forms of land use (in particular afforestation). In particular, it should exclude SAF derived from crops that compete directly with dedicated land for food/feed production. If some regions do not provide enough guarantees in terms of traceability and enforcement of sustainability criteria, their feedstocks may need to be excluded.

Specific forms of crop-based biomass that do not directly compete for land such as that derived from double cropping or unused degraded land, can still offer a sustainable source of feedstock for SAF production. These sources should be further researched and developed to ensure they can play a role in the decarbonization of aviation, subject to demonstrating that these crops do not contribute to additional cropland demand. Biomass supply from cover crops and unused degraded land could theoretically provide up to approximately 10% of total EU jet fuel supply by 2030.[23] These also offer potential positive externalities in the form of rural development, improved soil fertility and biodiversity.

2.2 Residual and waste lipids biofuels

The second major feedstock category for SAF is residual and waste lipids. This includes used cooking oils and animal fats (i.e. tallow), as defined in Annex IX Part B of the RED-II framework, as well as other diversified waste oil and fat sources.[24] At present, the majority of SAF production occurs via the conversion of vegetable or waste oils and fats to jet fuel via the HEFA process. This is currently the lowest cost and most widely commercialized production method, with the largest potential to grow production capacity in the short term.

Sources of feedstock for this production pathway, however, face a natural upper bound limit: there is a finite supply of waste oil/fat feedstocks given population, production and collection constraints (especially challenging for household rather than commercial waste sources). Additionally, there are other use cases for these feedstocks in multiple competing industries. Estimates of the total theoretical availability of waste and residues lipids indicate that SAF produced from these feedstocks could provide up to 5% of global aviation demand in 2030 via SAF, while European-sourced waste oils and fats could also cater for around 5% of European jet fuel demand.[25]

SAF produced from waste oils and fats, given the higher technological readiness of the HEFA conversion pathway, will play a key role in ramping up SAF production in the short term. Collection should be maximized to enable a rapid growth in production, while ensuring controls are in place to avoid any adverse effects, such as risks of illegal imports of palm oil mis-labelled as used cooking oil. Once the upper limit of SAF supply from waste oils is reached, however, other advanced feedstock sources and their associated production pathways will be essential to grow SAF volumes to the level required to achieve carbon neutrality in aviation.

2.3 Lignocellulosic and biowaste biofuels

To develop SAF beyond the limited volumes available from waste oils and fats, SAF from lignocellulosic and biowaste feedstocks will need to be developed. These feedstocks, e.g. agricultural and forestry residues or biogenic municipal solid wastes, are more abundant than sustainable crops and oil/fat wastes and could therefore underpin a more aggressive growth in SAF production. They could also be more sustainable than energy crops – from lifecycle carbon intensity, land use and biodiversity perspectives – if appropriate sustainability criteria are enforced. Key dimensions that still need to be tightly regulated include:

- Focusing on wastes and residues (e.g. forest and agricultural residues) rather than lignocellulosic production on dedicated cropland
- Banning collection from areas of high biodiversity, high soil erosion, and natural landscapes
- Ensuring sufficient forest and agricultural residues are left in situ to maintain soil health
- Excluding residues used for competing uses that cannot feasibly be replaced (e.g. animal bedding and feed, horticulture, etc.)Excluding residues sources from areas with weak institutions and high risks of corruption, which entails higher risks of non-compliance with those sustainability criteria

The truly sustainable supply of lignocellulosic and biowaste materials will still be constrained. Considering also practical collection constraints, it could theoretically represent sufficient biomass to supply up to two-thirds of total jet fuel demand, globally and in Europe, with CO_2 reductions of more than 65% (i.e. the RED-II limit in Europe). But demand for this type of feedstock will arise from multiple sectors of the economy outside aviation (e.g. in power and industry), and supply is likely to be lower than demand, which calls for a prioritization of use cases.

At present, the technological pathways for producing SAF from these lignocellulosic feedstocks remain at pilot and demonstration facility stages. While several production pathways are approved and certified by ASTM – i.e. Gasification + Fischer-Tropsch (F-T) and Alcohol-to-Jet (ATJ) – they have not yet reached commercial production at scale. Targeted policy support is required to rapidly bring those technologies to market and ramp up production capacity. This is a prerequisite to large-scale SAF uptake in aviation in the late 2020s and early 2030s.

2.4 Recycled carbon fuels

Recycled carbon fuels are liquid and gaseous fuels produced from the conversion of exhaust or waste streams of fossil fuel-based industrial applications or of non-biogenic/plastic municipal or industrial waste.[26] These fuels can contribute to a reduction in carbon emissions in the short to medium term by reusing fossil carbon twice. Exact lifecycle emissions compared to conventional jet fuel depend on the feedstock, production pathway and alternative methods of waste disposal. It will be important to undertake full lifecycle assessments of each type of recycled carbon fuel to ensure that they generate real GHG emissions reductions relative to conventional jet fuel, including indirect effects to ensure no additional demand for fossil fuels is created.[27]

In a context of multiple constraints on bio-feedstock availability and technology readiness, recycled carbon fuels could provide a useful additional source of SAF in the 2020s and 2030s. Regulations based on LCA GHG reduction thresholds should therefore provide provisions to allow a transition role for these types of recycled carbon fuels. These fuels, however, remain only partial decarbonization solutions and will no longer be available once upstream fossil-based products and processes are discontinued, so regulations should also anticipate their phase out.

2.5 Power-to-liquid fuels

The final technological pathway to consider in the SAF suite is power-to-liquid fuels (i.e. renewable fuels of non-biological origin, also called electro-fuels, synthetic fuels or synfuels). These are produced through the conversion of electricity into liquid hydrocarbons, via the electrolysis of water to produce hydrogen followed by synthesis with CO_2.

For this pathway to be sustainable in the long term, it must rely only on renewable or zero-carbon electricity input and on a renewable source of CO_2, in particular from direct air capture (DAC). In the short term, however, CO_2 from industrial waste sources will be cheaper and more readily available to develop initial volumes, prove production at scale, and drive learning curve effects. As for recycled carbon fuels, use of CO_2 from industrial waste sources enables a second use of fossil carbon atoms. A tightening of LCA GHG thresholds over time should progressively shift production towards direct air capture.

In principle, power-to-liquids are likely to represent the most scalable long-term option for SAF provision, given lower land use constraints than bio-based routes; energy produced by square kilometre is up to 100 times higher for solar than for biomass production.[28] Only small-scale pilot plants have, however, been developed to date. Current and projected costs remain prohibitively high for large-scale adoption, especially when relying on DAC. The ramp up of power-to-liquids production will crucially depend on a rapid drop in the cost of green hydrogen production and direct air capture, underpinned as far as hydrogen is concerned by the development of hydrogen use across multiple sectors of the economy. In that context, power-to-liquid fuels have the potential to eventually disrupt the economics of SAF if we mobilize investments in this decade to drive scale and reduce cost. Nonetheless, it is unlikely that these will play a large role in the decarbonization of European aviation over the next 10 years.

3 Timeline for SAF production ramp up

Analysis undertaken within the *Clean Skies for Tomorrow* initiative by the Energy Transitions Commission (ETC) and McKinsey & Company indicates that the production of SAF could increase significantly in Europe over the next 10 years if appropriate incentives were in place. Given the lead time required to build new production plants (approximately five years), growth in SAF output will remain relatively limited before 2025, unless policy drives a progressive shift of the existing biofuels production capacity from road transport to aviation. But European-based SAF production could possibly reach between 1.5 and 7 million tonnes per year by 2030 – amounting to between 2% and 10% of total pre-COVID-19 European jet fuel consumption. Strong policy support will be necessary to reach the highest projections.

Availability of SAF in Europe by 2030 will crucially depend on:

- The availability of truly sustainable crop-based biomass from low-ILUC sources and the existence and effective enforcement of tight sustainability criteria without which their use would not be acceptable to the aviation industry.

- The availability of waste oils and fat feedstocks for SAF production via the HEFA pathway, which could be enhanced by appropriate policy incentives for waste collection.

- The technological readiness and rate of early deployment of lignocellulosic and biowaste biofuels and power-to-liquids, which can be accelerated through RD&D support.

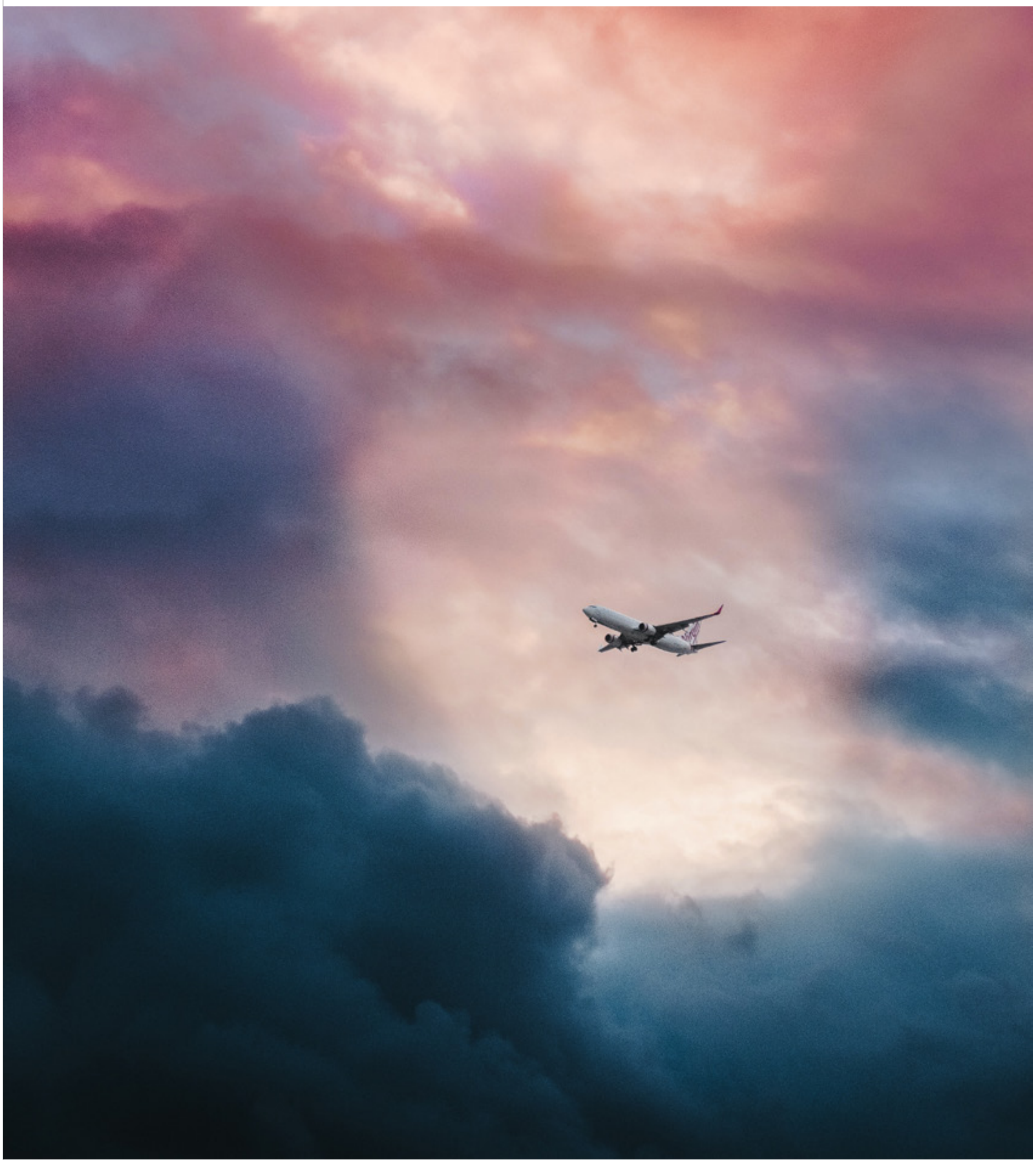
- The scale of imports of waste oil and lignocellulosic feedstocks for SAF production in Europe, given the necessary controls and potential bans on imports from regions with low environmental safeguards.

- The level at which existing and new low-carbon fuel capacity is prioritized for aviation versus road transport. This in turn depends on coherent policy development in Europe that emphasizes more efficient decarbonization pathways for road transport such as electric and hydrogen, freeing-up low-carbon fuels feedstock for SAF.

Based on these constraints, SAF produced from waste oil and fat-based feedstocks could represent approximately 5% of total European jet fuel consumption by 2030 (excluding imports), if output is prioritized for aviation. Assuming a limited uptake of crop-based SAF, the majority of future SAF output will therefore need to come from lignocellulosic/ biowaste biofuels and power-to-liquids. Rapid development of these pathways is therefore essential to the decarbonization of aviation.

Below: Unsplash/Leio Mclaren

4 Policy support for SAF ramp up



The key issue currently preventing the production and use of SAF from taking off is the price gap with fossil-based jet fuel, which remains prohibitively high (more than 100%-200% for the lowest-cost production method, i.e. HEFA, at pre-COVID-19 oil prices). The SAF supply chain faces a "chicken and egg" problem with supply and demand: costs will come down if production scales up (thanks to learning curve effects and economies of scale), but fuel providers are lacking a strong demand signal to increase production and demand is low due to the high price premium.

The current policy landscape does not adequately incentivize and de-risk investment in SAF. As the European Union and the UK refine their strategy to deliver their respective net-zero emissions targets, it is crucial that they establish a long-term, strategic policy framework that can provide greater certainty for investors and producers in the SAF value chain to drive production volumes up and prices down.

4.1 General design principles

" It is crucial that they establish a long-term, strategic policy framework that can provide greater certainty for investors and producers in the SAF value chain to drive production volumes up and prices down.

Europe needs a dedicated industrial SAF strategy and coherent long-term action plan to meet its GHG emissions targets. Over the course of an extensive dialogue with industry, government agencies and NGOs, the following key design principles were identified to ensure new policy frameworks created to support the low-carbon transition of aviation are as effective as possible:

– **The enemy is fossil carbon, not aviation.** Although behavioural changes, especially with regards to business trip practices, might evolve and slow down the growth of the aviation sector, aviation provides extraordinary societal benefits and remains essential to a functioning global economy. Policy should prioritize reducing GHG emissions from the industry – to eventually reach net-zero – but not prevent businesses and individuals from flying. To be most effective, policies should be directly related to the GHG emissions intensity of air travel.[29]

– **All policies should be feedstock and technology neutral** to allow for a range of bio-based and synthetic SAF production routes, only distinguishing fuels based on technology maturity levels (with greater support required for earlier-stage technologies) and on appropriate lifecycle carbon emissions and broader sustainability requirements (especially in terms of land use and biodiversity impact). These requirements should be tightened over time, shifting the lifecycle carbon-intensity threshold in line with the objective of reaching net-zero emissions by mid-century. To the extent that is possible under international law, policies may favour the use of domestic feedstocks over imports to avoid unnecessary supply chain emissions and mitigate risks of lower compliance with sustainability criteria.

– **The ramp-up of SAF use in Europe will necessarily be progressive** due to the fledgling nature of the technologies in question. Beyond existing SAF projects and airline commitments, limited progress in SAF output can be expected before 2025-2026 due to the lead time to build new SAF production capacity.

– **Targeted policy efforts should be dedicated to developing the supply of biofuels** from lignocellulosic/bio-waste feedstocks and of power-to-liquid fuels for aviation. This is crucial to prevent a stalling of the SAF ramp up once the upper bound of availability is reached from more accessible waste-oil sources such as UCO/AF.

  - Given high feedstock costs and cost of production technologies, it is unlikely that SAF can reach price parity with conventional jet fuel in the absence of a high carbon price in the next two to three decades (above €200 per tonne of CO_2 for the most advanced technologies.) Increasing SAF uptake will therefore require a combination of (a) short-term financial support to technology development and early deployment and (b) medium-term (2025 onwards) incentives for wider uptake throughout the whole aviation sector. The former set of policies can be progressively phased out as SAF become increasingly cost-competitive (via cost reductions and carbon pricing), while the latter set of policies can be progressively tightened as SAF become increasingly available.

– **Revenues from carbon prices on the aviation sector should be re-invested in SAF production/uptake and other measures to decarbonize aviation**, creating a positive feedback loop.

– **The key to driving up investment in SAF production is to provide fuel suppliers – and their financiers – with greater certainty on future markets**. The EU Commission should therefore announce in 2020 aviation policies to be enforced in the second half of the 2020s to incentivize investment in SAF production plants over the next five years. Policy frameworks should then remain in place for at least 10-15 years to ensure projects have a solid long-term business case.

- **Given supply constraints, sustainable bio-feedstocks should be prioritized for use in aviation**, where alternative decarbonization options are extremely limited, rather than other sectors of the economy like power and heat provision, where alternative, cheaper, more abundant and more energy-efficient decarbonization options are available. This also implies that policy frameworks should gradually transition biofuels production in Europe from a focus on road transport towards aviation. Direct electrification or indirect electrification (via hydrogen fuel cells) are increasingly more cost-competitive options for the decarbonization of road transport than biofuels.
- **European policies should be conceived so as to encourage and facilitate an acceleration of decarbonization efforts at a global level within ICAO**. They should take into account the international competitiveness of airlines, airports and fuels suppliers to prevent carbon leakage to countries with different policy frameworks. Regulations limited to intra-European flights (encompassing both the EU and the UK) would cover a significant proportion of total European traffic and fuel consumption. Intergovernmental discussions could progressively expand the scope of these accelerated decarbonization efforts to other major hubs outside of Europe.

4.2 Specific policy recommendations for EU and UK

European CST members have devised a policy package to support the adoption of SAF in Europe, which includes measures aimed at increasing SAF supply and demand. It is vital that these policies simultaneously boost SAF production and consumption in a strategic and sequenced manner to avoid supply bottlenecks and price volatility. Policy frameworks should also be coherent with the technically feasible pace of production ramp up described previously.

4.3 Four Priorities for supporting the development and early deployment of SAF

Given limits on the future supply of feedstock for commercially available SAF pathways, new technology pathways urgently need to be brought to market, despite their current lack of cost-competitiveness. They will require government support to bridge the “valley of death” and transition to commercial production. In parallel, even for the most technologically advanced HEFA pathways, the

first wave of deployment at industrial scale is more difficult to finance than conventional fuel plants, due to technology risks and to the financing premium associated with first-of-a-kind industrial-scale investments. Further direct and indirect support is therefore required to ensure SAF production can scale up and meet an increase in demand.

Those supply-side measures should be focused on the most sustainable and scalable production pathways, in particular biofuels from lignocellulosic feedstocks, biowaste, and power-to-liquids. Each of the following priorities to support SAF supply will be appropriate at a different stage of technology development.

Priority 1: Support innovation to bring lignocellulosic/ bio-waste and power-to-liquid pathways to market.

Bringing SAF uptake in Europe to a meaningful scale will not be possible by relying exclusively on the technology pathways that are commercially available today. Further research and development into SAF production technologies is therefore required and should be focused on technologies with the highest potential for cost disruption and with the most sustainable sources of feedstock – i.e. biofuels from lignocellulosic feedstocks and power-to-liquid pathways. The revision of the EU's innovation policy following the European Green Deal provides an opportunity to prioritize those innovation areas within the EU innovation spending. In parallel, the European Union could accelerate the certification procedure for new SAF technology pathways by contributing to the financing of the ASTM clearing house system – currently driven by the United States – to reduce appliance failure and lower the costs for certification.

Priority 2: Support SAF provision through price floors guaranteed by government during the early stages of deployment.

“ Bringing SAF uptake in Europe to a meaningful scale will not be possible by relying exclusively on the technology pathways that are commercially available today.

Growth in supply will be dependent on the existence of a market for SAF which is currently limited due to the price difference between SAF and conventional jet fuel. Policy mechanisms to secure a price floor for SAF output will be crucial for making new SAF plants economically viable, especially in the early stages of deployment, while regulations incentivizing SAF demand (e.g. fuel mandates) are not yet in place.

In the longer term, even as volume-based regulations start incentivizing uptake, greater certainty on the scale of the SAF market could still be insufficient to incentivize investment in new technology pathways, given the lower cost of first generation and waste-based SAF. Dedicated support mechanisms could therefore usefully support the first industrial-scale plants producing biofuels from lignocellulosic/biowaste feedstocks or power-to-liquid fuels.

At higher levels of market maturity, with a wider competitive set of producers, the implementation of systems such as contracts-for-difference schemes or scheduled auctions should be considered. This form of intervention has proven to be a success in the early stages of development of renewable electricity projects (e.g. wind and PV projects) rapidly driving down costs. It should, however, be noted that the pace of cost reduction is likely to be slower for bio-based SAF than for renewables as feedstock and conventional equipment represent a larger proportion of total costs.

Priority 3: Support early deployment by de-risking investment in the first wave of production facilities.

Even in a favourable policy context, investment in first-of-a-kind production facilities will entail a level of technology and commercial risks that lead to high financing costs for fuel providers. The difficulty in financing these projects also means that the timeline required to raise capital for SAF plants is excessively long compared to the required speed of decarbonization. This will likely remain true for the following wave of projects during the first decade of SAF deployment reflecting the limited track record of similar investments. Different forms of public financial support should therefore be used to help de-risk these projects and secure upfront private capital investment. This support could take the form of development capital and loan guarantees for SAF suppliers from European public investment funds, national government, regional development banks and international financial institutions

4.4 Driving SAF demand

While support to fuel providers is vital to increase production volumes over the next 10 years, it will be insufficient to provide a strong business case for the development of SAF plants at industrial scale in the absence of robust demand signals providing some certainty on future demand levels. In the short term, price-based incentives are unlikely to be sufficient to drive a switch to SAF in the aviation sector due to the extent of the fuel price gap. Volume-based regulations – i.e. a SAF blending mandate that could take the form of GHG emissions targets, renewable energy targets or sustainable fuels targets – are more likely to drive SAF uptake over the next 10 to 15 years. These regulations would have to include progressively higher targets over time at a pace that matches expected feasibility of supply ramp up.

Priority 4: Announce in 2021 a SAF blending mandate for European aviation to be enforced by no later than 2025 with a blending level increasing progressively over time to 2050.[30]

A SAF blending mandate would create an obligation for fuel suppliers/ airlines to provide a certain percentage of fuel from renewable sources or gradually reduce the GHG emissions intensity of their fuel output.

A SAF blending mandate would create an obligation for fuel suppliers/airlines to provide a certain percentage of fuel from renewable sources or gradually reduce the GHG emissions intensity of their fuel output. The obligation should initially apply to intra-EEA flights, ideally encompassing the EU and UK. In the EU, it could be implemented by including aviation as an obliged party to the next iteration of the Renewable Energy Directive (RED-II), the Fuel Quality Directive (FQD) or via a new separate mandate. This will serve as a powerful incentive to boost production and secure investment in SAF. Public financial support, however, will be required to compensate for the effect of competitive distortions, especially on intra-EEA feeder flights. Additional measures will be needed by 2030 at the latest to ensure the decarbonization of long-haul aviation.

For such a blending mandate to be effective, it would have to:

- Ensure lifecycle GHG emissions assessment cover emissions associated with producing, transporting and using the fuels, as well as significant indirect effects from land use change. They should also be combined with additional sustainability criteria, in particular with regards to land use and biodiversity:
  - Crop-based feedstocks that directly compete with land for food/feed production should be excluded.
  - SAF made from waste carbon or non-recyclable plastic in municipal solid waste should initially be included as compliance options.
  - The threshold in terms of lifecycle GHG emissions should be raised through time to drive a shift to the most sustainable forms of SAF and reach 100% by mid-century.
- Maximize fuel availability for aviation by:
  - Focusing incentives for the development of the bio-economy in Europe on use in the aviation industry rather than in other sectors of the economy, which benefit from alternative decarbonization options.
  - Respecting the constraints established in sustainability criteria above.
  - Ensuring the gradual transition of biofuels for use in aviation versus road, as part of a broader mobility strategy that supports a rapid electrification of surface road transport in Europe.
  - Incentivizing the build-up of multiple lignocellulosic/biowaste feedstocks and power-to-liquid facilities to produce SAF via methods such as ambitious sub-targets in the mandate – while taking care to avoid sudden price shocks.[31]
- Determine the most effective implementation mechanism:
  - Further analysis will be required to establish whether the mandate should be imposed on airlines versus fuel suppliers based on legal and practical implications.
  - Whether at the EU or national level, the most effective mode of compliance will need to be established, such as via a carbon intensity target[32] or a renewable fuel target.
- Be combined with market-based mechanisms:
  - All schemes should include a trading mechanism to allow companies to trade credits to comply with the target. Systems will need to be devised to manage over/under supply of SAF through a market stability mechanism (similar to the market stability mechanism in the EU ETS). For example, if the mandate target is not met, a buy-out scheme will need to be in place.
  - Ensure adherence to the obligation by setting the cost of non-compliance above the prospective cost of compliance.

Below: Unsplash/Joel Jasmin

5 Concluding remarks

The aviation industry is at a historical critical juncture. Amid arguably the worst crisis it has ever faced, it must also contend with finding a viable decarbonization strategy to preserve its social licence to operate and help avoid future climate crises. With appropriate government support, the current situation could offer an opportunity for the industry to reset itself onto a more sustainable path.

European members of the *Clean Skies for Tomorrow* initiative believe that Europe should pursue a combination of supply- and demand-side measures to accelerate the uptake of sustainable aviation fuels. This will unlock benefits from learning-curve effects and economies of scale, driving cost reductions and enabling faster sectoral decarbonization in Europe and beyond.

Signatories

This paper was co-developed in partnership with the members of the *Clean Skies for Tomorrow* coalition's European policy workstream.
The following participants have formally endorsed the viewpoints expressed within this paper.

Airbus Group

Deutsche Lufthansa AG

Deutsche Post DHL Group

Dubai Airports

Groupe ADP

Heathrow Airport

International Airlines Group

KLM Royal Dutch Airlines

Neste

Ørsted

Royal Dutch Shell

Royal Schiphol Group

SkyNRG

The Boeing Company

Velocys, Inc.

Contributors

World Economic Forum

Christoph Wolff
Head, Shaping the Future of Mobility

Kevin Soubly
Project Lead, Clean Skies for Tomorrow
kevin.soubly@weforum.org

Energy Transitions Commission

Faustine Delasalle
Director

Lloyd Pinnell
Aviation Lead
lloyd.pinnell@systemiq.earth

This paper was co-developed through the *Clean Skies for Tomorrow* coalition's European policy .workstream and was made possible through the invaluable contributions of all participants.

Contact
For questions about *Clean Skies for Tomorrow* and the Forum's Shaping the Future of Mobility Platform, contact Kevin Soubly kevin.soubly@weforum.org.

Endnotes

1. Relative to EU jet fuel consumption pre-COVID-19.
2. These recommendations constitute a collective view of the *Clean Skies for Tomorrow* European policy workstream. Members endorse the general message of the arguments made in this report but should not be considered to necessarily endorse all findings or recommendations unless otherwise noted.
3. IEA (2019), *Tracking Transport – Aviation*.
4. *European Aviation Environmental Report 2019*
5. IEA (2017), *Energy Technology Perspectives*.
6. Projections include impacts from the COVID-19 crisis. ATAG (2020), *Waypoint 2050*
7. IATA (2013), *Technology Roadmap*.
8. Changes in the positioning of fuel tanks and engines could indeed be necessary.
9. SESAR Joint Undertaking. http://www.sesarju.eu/
10. RMI (2011), *Reinventing Fire Transportation, Transportation Sector Methodology.*
11. Air Transport Action Group (2018), *Aviation Benefits Beyond Borders.*
12. The Boeing Company (2015), *Trends in Fleet and Aircraft Retirement.*
13. IATA (2013), *Technology Roadmap.*
14. ICAO (2016), *On Board a Sustainable Future.*
15. The issue of market distortions (e.g. from feeder flights) should also be addressed in this scheme.
16. The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is an emission mitigation scheme for the global airline industry, developed by the International Civil Aviation Organization (ICAO) and adopted in October 2016. Signatories have agreed to offset any annual increase in total CO_2 emissions from international civil aviation above 2019 levels. The scheme covers approx. 75% of international flights. The first phase of the scheme is voluntary (2021-2027) and the second part (2027-2035) is mandatory for signatories.
17. Latest publicly available data for 2017. The installed potential production capacity is considerably higher (c. 2.5 million tonnes, or 3 billion litres), but plants currently dedicate most fuel output to the road sector.
18. Approx. 300%-400% relative to current oil prices due to the ongoing COVID-pandemic.
19. ETC (2019), *Mission Possible, Sectoral Focus: Aviation*
20. Sustainable Aviation (2020), *Sustainable Aviation Fuels Roadmap*.
21. E.g. Direct Sugars to Hydrocarbons (DSHC), Hydrothermal Liquefaction (HTL), Aqueous Phase Reforming (APR) and other pathways currently under development.
22. USDA Foreign Agricultural Service, Global Agricultural Information Network, EU-28 Biofuels Annual 2019.
23. World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*
24. This includes waste oils and fats included in Part A Annex IX of the EU Renewable Energy Directive II (e.g. tall oil pitch, palm oil mill effluent) and other sources - tall oil, fish oil, technical corn oil, etc.
25. World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*; Waste oil and fats are subject to competing demand from various sources. This figure does not include potential imported feedstocks from other regions.
26. Residual municipal and industrial waste streams (post-recycling) are composed of a mix of biogenic and non-biogenic/ plastic waste. It is typically economically unfeasible to separate these waste streams, so provisions will need to be made for liquid fuels produced from these mixed sources. Policy efforts should equally focus on reducing upstream waste creation as much as possible.
27. The current formulation of the EU RED-II does not issue formal guidelines on carbon intensity calculations for recycled carbon fuels.
28. World Resources Institute (2015), see: https://wriorg.s3.amazonaws.com/s3fs-public/uploads/WRI_responds_to_Argonne_critiques.pdf
29. This does not preclude a rise in ticket prices to cover decarbonization costs, which may be inevitable given the cost premium for SAF. The distributional implications of this measure are, however, likely to be limited, especially relative to the effect of support for renewables in other sectors, e.g. power.
30. Members of the CST initiative aim to publish more precise recommendations on appropriate levels for a blending mandate in the coming months.
31. Respecting the categorization established in the EU RED-II frameworks and the European Commission (2017), Sub-Group on Advanced Biofuels. This defines "advanced" biofuel pathways according to feedstocks and includes biomass from low-ILUC crops (including the starch and oils from cover crops) and certain waste oils and fats (e.g. tall oil, POME etc.).
32. See: California Low Carbon Fuels Standard (LCFS) system.

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org